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OPTIMISATION STRATEGIES FOR CONTINUOUS MONITORING OF DENSELY SENSED BUILDINGS

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ABSTRACT

Continuous Commissioning (CC[®]) of buildings is a rapidly growing sector within facility management services linked with a long-term demand for efficient tools and strategies directed onto acceptable tenant comfort, reduced energy consumption and cost of buildings maintenance.

Continuous building monitoring techniques are used to provide the best possible level of detail for the analysis of building energy performance. Additional software/hardware installations can be required to provide effective building commissioning and monitoring. However in many cases, when this process is initiated, these additional installations (e.g. sensors, sub-meters, actuators etc.) can exceed the capabilities of the current Building Management System (BMS). Furthermore, there are difficulties in predicting building occupancy trends which very often do not correlate with the expected energy demand when buildings are in use or operation.

This paper is based on the ongoing work and interim results of “ITOBO” project [1] and “CAMPUS 21” project [2], both focusing on the energy-efficient operation of buildings and spaces.

The management experience of the authors combined with the research partners’ expertise from multiple sectors, such as Construction & Facilities Management, Building Services Systems Manufacturers, energy research centres and Energy Providers. Two buildings of the campus of University College Cork, Ireland are used as a case studies to demonstrate the process of BMS commissioning, data collection and evaluation. These are the Environmental Research Institute (ERI) and the Civil and Environmental Engineering (CEE) both of which are educational buildings of contrasting ages. The objectives of this paper, based on a series of experiments, are to:

- Describe the continual monitoring algorithm outside of the trademarked CC[®] description;
- Display the identification methods of various faulty operations in the HVAC system by analysis of collected data – ERI example;
- Establish an understanding of the relationship between sensor density and sensing accuracy for a single physical parameter at a spatial and temporal level – CEE example;
- Outline the possible energy saving measures for the HVAC systems commissioned.

It is expected that the “ITOBO” and “CAMPUS 21” experimental results can be used to provide automated feedback to the Building Management System which can then be further used to improve HVAC control and efficiency.

Keywords: Continuous Commissioning; Building Control; Energy Efficiency; BMS

INTRODUCTION

The energy consumed during the operational phase of a building is one of the major contributors to increasing energy use in Europe. Typically it comprises space conditioning (heating and cooling), lighting, heating of water, and running various appliances. Increasing the efficiency of energy use will have a significant impact on European energy consumption, and consequently reduce carbon dioxide production as well as reduced dependency on imported energy and improved environmental conditions. New operational and maintenance management strategies need to be developed in order to enable the intelligent and efficient use of the energy consumed.

Further new technologies and the liberalisation of the energy market across the EU greatly expand the range of energy service providers, as well as associated industries and services, e.g. smart meters developers, Facility Management and Energy Commissioning companies, Neighbourhood Management System (NMS) providers etc. This is a trend that is set to continue, thus the adoption of a sophisticated Building Management Systems (BMS) and Energy Management Systems (EMS) as a systematic process for continually improving energy performance is crucial in monitoring and controlling building performance.

Effective management of energy use in buildings makes perfect business sense - it cuts the costs, decreases greenhouse gas emissions (for associated restrictions and penalty costs etc.), reduces exposure to volatile energy prices and improves company's image if this is commercial property. However many companies are reluctant to focus on energy management or to invest in energy efficiency measures as they cannot accurately quantify the maintenance costs of their facilities. Nevertheless, there are many good examples which can prove that a systematic approach to managing energy performance can be successfully combined with the priorities and requirements of many companies [3]. Figure 1 below shows how energy consumption behaves over time when a company occasionally implements commissioning actions in response to maintenance and/or rising energy costs, versus implementation of continual facilities' commissioning. Energy consumption will continue to cycle and go out of control if an organisation does not manage its energy use on a regular basis and doesn't make building's commissioning a part of normal scheduled business operations.

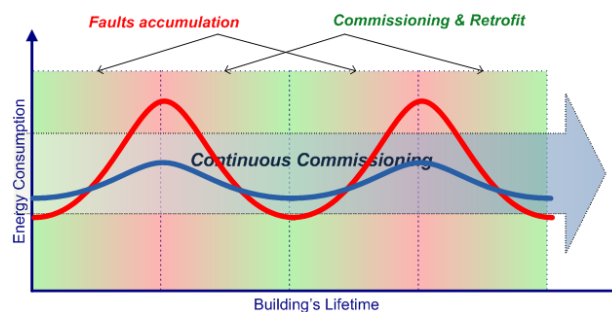


Figure 1: “Ad hoc” VS “Continual Commissioning” approaches to building energy management

An essential part of a BMS efficiency for energy management is its monitoring capabilities. Quality data that is collected and correctly evaluated helps to highlight the possible areas for operational improvements more effectively. Analysing historical data, on a regular basis, further assists BMS operators to track changes in building functionality and occupant energy-related behaviour over the longer periods, improving their ability to react accordingly.

Maintaining building BMS systems can require significant efforts for the building management team. The performance of a BMS can be significantly reduced due to improper/incompatible equipment installation, degradation and failures, or even inappropriate

settings of operational sequences. Usually building maintenance staff can be alerted to mechanical malfunctions through alarms when certain parameters exceeds a pre-set limits. In theory this can be set to occur prior to a malfunction being critical, thus enabling maintenance personnel to act on time and repair the damage before system fails. However, in reality the majority of these minor events are often postponed. These negligible faults, mistakes and mismatches in operational schedules then simply accumulate over time. This leads to situation where the facility manager makes often ad-hoc alterations to the BMS settings that adversely affect the building's energy efficiency, and it's deteriorating over time.

All of the facts presented above, as well as the results of multiple research projects and energy-related literature developed over the last decade, have only confirmed to buildings owners and facilities managers that most of their buildings do not function at their maximum performance level, consuming extra energy and operational expenses. Possible reduction of the building maintenance costs is just one incentive for employing a program for regular commissioning processes (can be named as On-going Commissioning, Continual Monitoring, or Continuous Commissioning (CC®) [4]).

METHOD

Continual BMS monitoring, especially in densely sensed buildings, is one such on-going commissioning process incorporating specific diagnostic tools for gathering energy-related data. It is used for energy benchmarking, data acquisition and following analysis and BMS optimisation. This includes analysis of the BMS alarms and faults information, as well as information and alarms of missed/censored data. Figure 2 below represents the data-related steps of ongoing BMS commissioning.

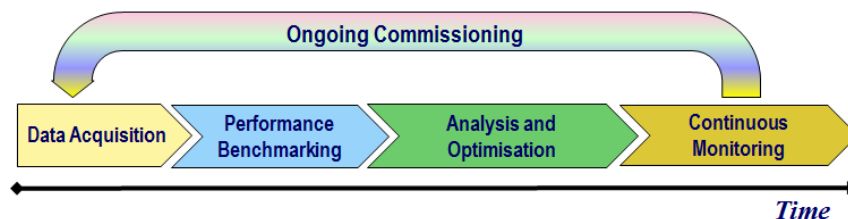


Figure 2: Data-related steps of ongoing BMS commissioning

Closely and continually working with incoming data will:

- provide energy managers with information about the current status of systems' operations,
- leading to how to adjust these systems,
- aiming to maintain or increase their efficiency.

Collection of building information, from architectural and mechanical drawings, specifications of equipment, BMS schedules and operational sequences, is the first step of the process for commissioning specialists. Benchmarking, in our case, is a process of comparing the actual recorded building energy performance data with guides of performance from a large number of reference buildings in the same region. This comparison can show if the commissioned building performs worse, similar to, or better than comparable buildings. Typically building performance benchmarking requires the development of sensible Key Performance Indicators (KPIs), which also can be called as Energy Performance Indicators (EnPI) in connection with an Energy Management System within buildings. These KPIs should be simple, understandable, measurable, objective, boundary containing, verifiable and sensible for the use case figures.

We should also differentiate between two types of these key figures, Absolute and Relative. An Absolute Key figures, for example, could be a total water consumption [m^3], total natural gas consumption [m^3], total number of employees, total energy consumption of lighting [kWh], total energy consumption of heating [kWh], total costs of gas and water [€] etc.

The Relative Key figures are developed by referencing these Absolute Key figures with reference values, e.g. energy consumption per m^2 , employees per produced piece, energy consumption per employee etc. These KPIs should be extendable and scalable for different use cases and reflecting the needs of different stakeholders.

RESEARCH BUILDINGS DESCRIPTION

As described this study focuses on the ERI and CEE buildings located on the main campus of University College Cork, Ireland. Figure 3 below.



Figure 3. ERI (left) and CEE (right) buildings on the UCC campus

The ERI building is the most densely sensed building on the UCC campus and operates as a “Living Laboratory”. Building performance data from the CYLON BMS system is provided by more than 180 wired sensors doing 13 different types of measurements, including indoor environment and outdoor weather conditions, along with integrated actuators and sub-meters. This building features many energy systems including solar collectors (SC, evacuated tube & flat plate) for pre-heating of the Domestic Hot Water (DHW); geothermal (88 kW Heat Pump with aquifer open loop); cooling and air handling (6 heat pumps (2.2 kW) for cold rooms, 4 AHUs for Labs (incl. heat recovery) and a gas fired boiler (163 kW) as back-up for the other systems.

The CEE building is a three story structure with solid 500 mm redbrick walls and 30 mm external roughcast plaster. The building consists of large lecture halls, computer labs, offices and corridors. Heat energy is supplied to the CEE Building from the main campus steam distribution network. The steam from the network, , enters the CEE Building by means of a heat exchanger in the plant room on the ground floor. [5] BMS-controlled thermostatic radiator valves (TRV) are in place on all radiators in the CEE building.

RESULTS

Currently, the energy consumption and production data aggregated from the sites described above is very detailed. Discussed below are the 2012 natural gas consumption data trend plus the data (gathered from integrated heat meter) reflecting energy saved by the solar and geothermal systems. The following figures will graphically show the energy consumptions and savings, allowing qualitative KPIs development, benchmarking, data analysis and buildings’ optimisation.

Data analysis results - ERI building

When assessing the contribution the solar array makes to overall DHW demand in the ERI building, it was necessary first to analyse the diffuse solar radiation levels for the year 2012.

By using data classification techniques, the average monthly diffuse solar radiation values were analysed as shown in Figure 4 below.

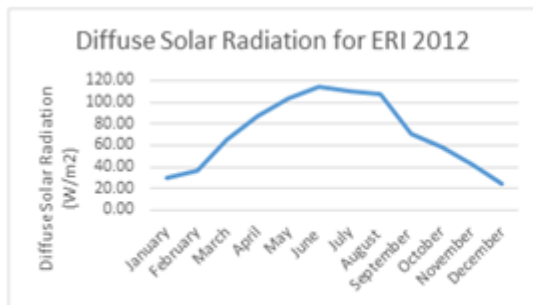


Figure 4. Diffuse Solar Radiation measured on roof of ERI, 2012

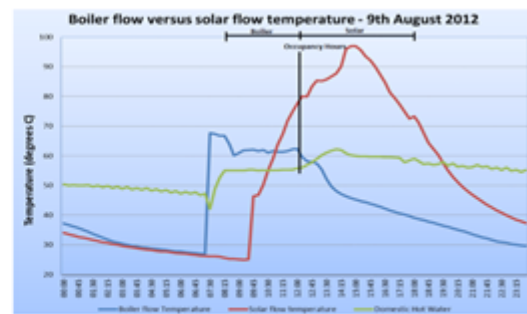


Figure 5. Boiler, solar flow and domestic hot water temperatures, ERI 2012

Using manual data mining analysis techniques, such as data classification and association, it was possible to examine the DHW system performance, so the 9th August 2012 was selected as a good example to demonstrate (Figure 5) within associated occupancy hours of the ERI building. This analysis uncovered an error in the BMS scheduling where the boiler starts early in the day and therefore negates any potential contribution from the solar collectors. This was found to be the case for the majority of the days analysed where high solar radiation could have reduced the need for boiler use. If boiler's schedule will be changed to start 4 hours later it will save up to 80m³ of natural gas per similar day. For the year 2012 the estimated potential savings equals to 5.7% of the overall gas consumption, or 5.5 tons less of CO₂ emission plus reduced operation of the boiler means longer equipment lifecycles.

This also demonstrates a demand for automated commissioning software tools to highlight days with expected higher solar radiance, so boiler scheduling adjustments could be done automatically for the following day. The overall performance of the DHW system could be further improved by continually checking the data available from a various sensors and heat meters available in order to set the BMS scheduling more efficiently.

Data analysis results - CEE building

In order to establish an understanding of the relationship between sensor density and sensing accuracy for a single physical parameter (air temperature, °C) at a spatial and temporal level, the CEE109 (Computer Laboratory) was taken for analysis. This room is occupied from Monday to Sunday, between the hours of 08.00 and 22.00; however, occupancy levels vary greatly within this time period. There are two temperature sensors installed in this room. Sensor 1 is located next to the access door, and Sensor 2 is located close to the radiator.



Figure 6. CEE109 Sensor Placement

For the purpose of this analysis, these two sensors' readings were taken as the extreme temperatures in the room. Sensor 1 reads the minimum temperature in the room, while sensor 2 reads the maximum. The difference in readings varies in 2-3°C. This is significant difference, which can cause disruption to BMS operation. An interpolation technique was applied to get the mean of these two data entries, from the week January 7th to 13th (Saturday to Friday) as example.

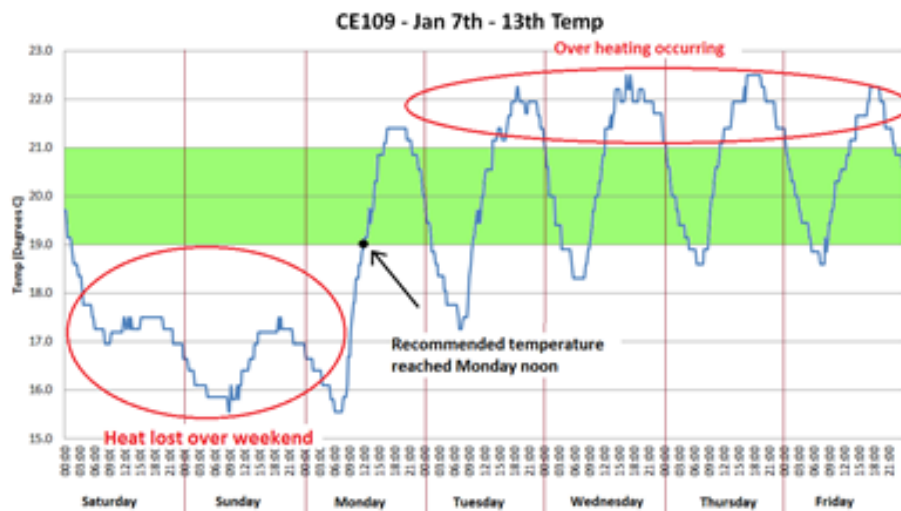


Figure 7. Interpolated temperature readings within the room CEE109

The thermal comfort analysis was based on CIBSE “Guide A” recommended operating temperatures for the four different room types analysed. It is clear that significant amount of heat was lost through infiltration and fabric losses over the weekend period, when the building was not being heated. This is due to the building being an older structure, when building standards were nowhere near as stringent as they are now. Improved insulation of the external walls would reduce the heat lost over the weekend. Correct positioning of sensing devices is important for adequate control procedures and BMS scheduling.

CONCLUSION

On-going/Continuous building and BMS commissioning, in common sense understanding, is a normal process of planned check-ups and maintenance procedures directed on maintaining buildings at their maximum performance level. The aim of this paper was to highlight the importance of regular attention from building energy manager to BMS and its operational processes through precise analysis of incoming data for development of reliable conclusions and consequences. Freedom in terminology will also provide more flexibility in selection of specific software tools, equipment and operations, as well as in adoption of the unique for each building commissioning techniques. It is great though that a well-known and experienced organisation such as Energy Systems Laboratory (ESL) is promoting same ideas.

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